(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number : **0 501 559 B1**

(12) # EUROPEAN PATENT SPECIFICATION

(45) Date of publication of patent specification : **07.06.95 Bulletin 95/23**

(51) Int. Cl.[6] : **G01D 5/26**

(21) Application number : **92200450.2**

(22) Date of filing : **18.02.92**

(54) **Process and apparatus for absolute interferometric measurements of physical magnitudes.**

(30) Priority : **27.02.91 IT MI910509**

(43) Date of publication of application : **02.09.92 Bulletin 92/36**

(45) Publication of the grant of the patent : **07.06.95 Bulletin 95/23**

(84) Designated Contracting States : **DE DK FR GB NL**

(56) References cited :
EP-A- 0 359 666
DE-A- 3 044 183
US-A- 4 890 922

(73) Proprietor : **CISE S.p.A.**
Via Carducci, 14
I-20123 Milan (IT)

(72) Inventor : **Gusmeroli, Valeria**
Via Cimabue, 15
I-20148 Milano (IT)
Inventor : **Martinelli, Mario**
Via Agadir, 16/B
I-20097 San Donato Milanese, Milano (IT)

(74) Representative : **Mittler, Enrico et al**
c/o Marchi & Mittler s.r.l.
Viale Lombardia, 20
I-20131 Milano (IT)

EP 0 501 559 B1

Note : Within nine months from the publication of the mention of the grant of the European patent, any person may give notice to the European Patent Office of opposition to the European patent granted. Notice of opposition shall be filed in a written reasoned statement. It shall not be deemed to have been filed until the opposition fee has been paid (Art. 99(1) European patent convention).

Description

The present invention relates to a process and an apparatus for absolute interferometric measurements of physical magnitudes.

The term interferometric measurements means measurements based on the assessment of the phase shift between two components of a light beam emitted by a light source and received by a detector.

The use of an interferometric measurement technique allows, for example, the execution of a measurement of distance of a mirror target in a classical interferometer such as, for example, that of Michelson.

As is known, the latter comprises essentially an optical beam splitter constituted by a semitransparent plate arranged at 45° to the direction of propagation of an incident beam, a reference mirror in a fixed position and a target mirror in a variable position, aligned along the direction of reflection and along the line of transmission of the incident beam, respectively. The latter, passing through the splitter, is thus in part reflected toward the reference mirror and in part transmitted toward the target mirror. The beams hitting the mirrors are reflected by the same and each of them, upon meeting the splitter again, is, as above, in part reflected and in part transmitted. The beam's reflected part coming from the target mirror and the beam's transmitted part coming from the reference mirror are aligned along the same direction of propagation which leads them to the input of a detector, where they interfere giving rise to an interference figure. From this it is possible to deduce the phase shift and thus the difference in the paths travelled by the two beams between the splitter and the reference and target mirrors, respectively, that is, in short, the distance of the target mirror.

Another use of the interferometric technique allows the measurement of physical magnitudes of a different type, such as, say, temperature, deformation and pressure, using optical fibres as sensors.

In this respect there are two methods for executing these measurements.

A first method, called the guided-wave method, uses a pair of optical fibres, one of which is used as a reference fibre, while the other is used as a measurement fibre, immersed in the area subjected to measurement. The two fibres are coupled together through a coupler at the output of a light source, say, a narrow-band laser source, and then recoupled beyond the measurement area through a second coupler located at the input of a detector. In general, the presence of a particular physical parameter alters the speed of propagation of a light beam in an optical fibre. As a consequence of this, the two components of the light beam emitted by the light source, passing through the optical reference fibre and the optical measurement fibre, respectively, shall arrive at the detector with a phase shift between them and, by measuring the phase shift itself, it shall be possible to go back to the determination of the physical parameter that has had an effect on the measurement fibre.

A second method provides for the use of a single fibre having a high birefringence. It is known that the presence of particular physical parameters has a different effect on the two bias modes emerging from an optical fibre having a high birefringence. The corresponding components of the light beam, after they have been projected on the same plane by a biasing unit located at the extremity of the fibre, shall enter the detector with a phase shift and from the measurement of the corresponding phase shift it shall be possible to go back to the determination of the physical parameter to which the fibre has been subjected.

The application of such interferometric techniques allows the determination of the phase shift between the components at input to the detector only with multiples of less than 2π, thus in an incremental and a "non-absolute" manner.

A known technique for executing absolute interferometric measurements provides for the frequency of the light beam emitted by the source to be made to vary according to a predetermined law, in particular sinusoidally. At the output of the interferometer there will thus be obtained a modulated beam in phase with the depth of modulation

$$D\phi = 2\pi D l D f / c$$

where Dl is the difference of optical path between the two arms of the interferometer, Df is the frequency shift caused by the modulation and c is the speed of light.

With the current modulation techniques, which in a semiconductor laser source are based in short on the variation of the current I_o of the source, Df cannot be very large because this would mean a large variation of I_o with inevitable functional drawbacks of the source.

It thus follows that according to the known art it is possible to obtain only a limited depth of modulation and thus a fairly modest measurement sensitivity of Dl.

The object of the present invention is to accomplish a process and an apparatus for absolute interferometric measurements, with which it is possible to obtain a high depth of phase modulation of the interferometer.

According to the invention such object is attained through a process for absolute interferometric measurements of physical magnitudes, comprising the delivery of a light beam from a source, the frequency modulation of said light beam, the phase shifting of components of the light beam as a function of the physical magnitude to be measured, the detection and the measurement of the phase shift of said components of the light beam, characterized in that said delivery is executed so as to produce a wide-band

light beam and said modulation is executed by means of pass-band filtering process centred on a frequency that is made to vary with a predetermined law.

According to the invention there is also accomplished an apparatus for absolute interferometric measurements of physical magnitudes, comprising a light beam source, means for the frequency modulation of said light beam, means for splitting and recombining beams to cause the splitting of the light beam into two components with a mutual phase shift dependent on the physical magnitude to be measured and a detector suitable for detecting said components of the light beam and for measuring their mutual phase shift, characterized in that said light source is a wide-band source and said means for modulating the light beam are constituted by a pass-band filter centred on a frequency that is made to vary according to a predetermined law.

In this way the introduction of the filter downstream from the wide-band source allows the accomplishment of a frequency modulation of the light beam with a high depth of modulation which makes it possible to obtain absolute interferometric measurements of the difference of optical paths with a high sensitivity.

In particular said wide-band source is a superluminescent laser source and the filter's central frequency, that can, for example, be of the interferential type or of the Fabry Perot type, is made to vary with a sinusoidal law.

According to a first embodiment the means for splitting and recombining the beams comprise an optical beam splitter with a semitransparent lamina, which splits the light beam into a reflected component directed toward a reference mirror and into a transmitted component directed toward a target mirror that can be placed at a variable distance from the optical splitter and recombines said components into a single beam after reflection on the part of said mirrors, so that the phase shift of said recombined components is indicative of the variable position of said target mirror.

According to a second embodiment, the means for splitting and recombining the beams comprise an optical reference fibre and an optical measurement fibre connected at the extremities by input and output optical couplers. The optical measurement fibre is subjected to a particular physical magnitude suitable for inducing a difference between the time of propagation of the component of the light beam passing through it and that of the component of the light beam passing through the reference fibre. The detector receives the components of the light beam coming from the abovementioned fibres and on the basis of the corresponding phase shift allows the assessment of the abovementioned physical magnitude.

According to a third embodiment the means for splitting and recombining the beams comprise an optical fibre having a high birefringence immersed in a particular physical magnitude suitable for having a different effect on the speeds of propagation of the two components of the light beam that propagate according to the fibre's two bias modes. The detector receives said components of the light beam and on the basis of the corresponding phase shift allows the assessment of the abovementioned physical magnitude.

The features of the present invention shall be made more evident by the embodiments illustrated as non-limiting examples in the enclosed drawings, wherein:

Fig. 1 illustrates a first embodiment of the apparatus according to the invention;

Fig. 2 illustrates a second embodiment of the apparatus according to the invention;

Fig. 3 illustrates a third embodiment of the apparatus according to the invention.

With reference to Fig. 1, the apparatus comprises a wide-spectrum superluminescent source of light 1, such as, say, a laser source of the type RCA 86063 F-15-TC with a central wavelength of 850 nm, spectrum amplitude 20 nm.

It also comprises a collimator 2 and an interferential filter 3, such as, say, a Corion filter S10-850 with a central wavelength of 850 nm, spectrum amplitude 10 nm. The angular position of the filter 3 with respect to its axis is made to vary in an oscillating manner with a sinusoidal law by a special device 13 (for example, a galvanometer) supplied with a sinusoidal signal; as an alternative, it is possible to use a filter of the Fabry Perot type, of which the length of the cavity that houses the refringent means or the latter's refraction index is made to vary (for example, if the refringent means is an electro-optical crystal, by causing the voltage applied across the crystal itself to vary). A desired law and depth of frequency modulation of the light beam at input is thus guaranteed.

In cascade to the filter 3 there is connected, through an optical fibre 12, an interferometer 4. The latter comprises an optical beam splitter 5, of the bias-difference type, constituted by a semitransparent plate 23 arranged at 45° to the direction of propagation of the incident beam, a reference mirror 6 integral with an oscillating support 14 operated by a saw-tooth signal so as to give a carrier to the light beam reflected by it, a target mirror 7 with a position variable with respect to a support 11, a bias analyser 15 and a detector 8. Between the optical beam splitter 5 and the mirrors 6, 7 there are also interposed quarter-wave laminae 9, 10 suitable for introducing 45° phase shifts in the light beams passing through them.

According to this first embodiment the apparatus works as a detector of the phase shift of the components of the light beam coming from the two mirrors 6, 7 arranged at a different distance with respect to the optical beam splitter 5 and is thus suitable for de-

termining the position of the target mirror 7.

In particular the light beam at output from the source 1 is sent to the collimator 2 suitable for forming a collimated beam. The beam at output from the collimator 2 passes into the filter 3, where it is frequency modulated with a sinusoidal law, and then through the optical fibre 12 it is sent to the interferometer 4. The beam impinges upon the semi-transparent plate 23 of the optical beam splitter 5 and is thus separated into a reflected component and into a transmitted component, corresponding to two different bias modes of the incident beam. They are sent to the reference mirror 6 and to the target mirror 7, respectively, which reflect them back. The components of the beam thus travel twice through the quarter-wave laminae 9, 10, a first time to go and impinge upon the mirrors 6, 7, a second time after being reflected by the mirrors themselves. In this way, the component of the beam splitter 5 previously reflected is now transmitted and, vice versa, the component previously transmitted is now reflected. The two components thus recombine into a single beam whose bias modes are projected on a common plane by the analyser 15. This recombined beam is received by the detector 8, which supplies at output an electrical signal that is proportional to the interference signal, that contains the desired phase shift term $D\phi$.

Since such phase shift is the result of the different distances of the mirrors 6, 7 from the spliter 5, the signal at output from the detector 8 thus contains information that is indicative of the distance of the target mirror 7 from the optical beam splitter 5 and thus of the position of the target mirror.

With reference to Fig. 2, a second embodiment of the apparatus according to the invention provides for the interposition, between the filter 3 and the interferometer 4, of an optical reference fibre 21 and of an optical measurement fibre 22 coupled by means of input and output couplers 19, 20.

The interferometer 4 in this case has only a function of initial calibration, allowing the compensation of possible differences, even if very small, in the length of the fibres 21, 22. For this purpose the distance of the target mirror 7 from the optical beam splitter 5 is adjusted so that in the absence of environmental perturbation on the fibre 22 the times of propagation of the components of the light beam that passes through the fibres 21, 22 are the same.

According to this embodiment, once the initial calibration operation has been executed, the optical measurement fibre 22 is subjected to a particular physical magnitude, such as a temperature, a deformation, a pressure and so on, symbolised with the dotted-line 18, that has the effect of changing the speed of propagation of the component of the light beam emitted by the source 1 that passes through it with respect to that of the light beam that passes through the reference fibre 21. Due to this perturbation the components of the light beam coming from the two fibres enter the interferometer 4 and thus the detector 8 with a given phase shift. The phase shift between said components is thus indicative of the particular physical magnitude to which the fibre 22 is subjected.

With reference to Fig. 3, according to a third embodiment, the apparatus provides for the presence of a fibre 32 having a high birefringence interposed between the filter 3 and the interferometer 4.

According to this embodiment, once the initial calibration operation has been executed in the manner described with reference to Fig. 2, the optical fibre 32 is subjected to a particular physical magnitude, indicated with the dotted line 28. The latter has a different repercussion on the two bias modes of the light beam, in the sense that the speed of propagation of the component of the beam according to one bias mode is different from that of the component according to a perpendicular bias mode. As already described with reference to Fig. 2, the components of the light beam corresponding to the two bias modes enter the interferometer 4 with a given relative phase shift and are thus received by the detector 8 with the same phase shift. As a result of this it is possible to assess the physical magnitude to which the fibre 32 is subjected.

Claims

1. Process for absolute interferometric measurements of physical magnitudes, comprising the delivery of a light beam from a source (1), the frequency modulation of said light beam, the phase shifting of components of the light beam as a function of the physical magnitude to be measured, the detection and the measurement of the phase shift of said components of the light beam, characterized in that said delivery is executed so as to produce a wide-band light beam and said modulation is executed by means of pass-band filtering process centred on a frequency that is made to vary with a predetermined law.

2. Process according to claim 1, characterised in that said predetermined law is a sinusoidal law.

3. Apparatus for the accomplishment of the process described in claim 1, comprising a light beam source (1), means (3, 13) for the frequency modulation of said light beam, means for splitting and recombining beams (5; 21, 22; 32) to cause the splitting of the light beam into two components with a mutual phase shift dependent on the physical magnitude to be measured, and a detector (8) suitable for receiving said components of the light beam and for measuring their mutual phase shift,

characterized in that said light source (1) is a wide-band source and said means (3, 13) for modulating the light beam are constituted by a pass-band filter (3) centred on a frequency that is made to vary according to a predetermined law.

4. Apparatus according to claim 3, characterised in that said predetermined law is a sinusoidal law.

5. Apparatus according to claim 3, characterised in that said source (1) is a superluminescent laser source.

6. Apparatus according to claim 3, characterised in that said filter (3) is of the interferential type.

7. Apparatus according to claim 3, characterised in that said filter (3) is of the Fabry Perot type.

8. Apparatus according to claim 3, characterised in that said means for splitting and recombining beams (5; 21, 22; 32) comprise an optical beam splitter (5) with a semitransparent lamina (23), which splits the light beam into a reflected component directed toward a reference mirror (6) and into a transmitted component directed toward a target mirror (7) that can be placed at a variable distance from the optical splitter (5) and recombines said components into a single beam after reflection on the part of said mirrors (6, 7), so that the phase shift of said recombined components is indicative of the variable position of said target mirror (7).

9. Apparatus according to claim 8, characterised in that said optical beam splitter (5) is of the bias-difference type and there are two quarter-wave laminae (9, 10) interposed between said beam splitter (5) and said mirrors (6, 7).

10. Apparatus according to claim 3, characterised in that said means for splitting and recombining beams (5; 21, 22; 32) comprise an optical reference fibre (21) and an optical measurement fibre (22) connected at the extremities by input and output couplers (19, 20), said optical measurement fibre (22) being subjected to a physical magnitude (18) suitable for determining the difference between the time of propagation of the component of the light beam that passes through it and that of the component of the light beam that passes through the reference fibre (21).

11. Apparatus according to claim 3, characterised in that said means for splitting and recombining beams (5; 21, 22; 32) comprise an optical fibre (32) having a high birefringence subjected to a physical magnitude (28) suitable for having a different effect on the speeds of propagation of the two components of the light beam that propagate according to the fibre's two bias modes.

Patentansprüche

1. Verfahren für interferometrische Absolutmessungen physikalischer Größen, umfassend die Abgabe eines Lichtstrahls von einer Quelle (1), die Frequenzmodulation dieses Lichtstrahls, die Phasenverschiebung von Komponenten des Lichtstrahls als eine Funktion der zu messenden physikalischen Größe, die Erkennung und die Messung der Phasenverschiebung der Komponenten des Lichtstrahls, **dadurch gekennzeichnet,** daß die Abgabe so erfolgt, daß ein Breitbandlichtstrahl erzeugt wird, und die Modulation mittels eines Durchlaßbereichfilterverfahrens ausgeführt wird, das auf eine Frequenz zentriert ist, die entsprechend einem vorgegebenen Gesetz geändert wird.

2. Verfahren nach Anspruch 1, **dadurch gekennzeichnet,** daß das vorgegebene Gesetz ein Sinusform-Gesetz ist.

3. Vorrichtung zur Durchführung des in Anspruch 1 beschriebenen Verfahrens, mit einer Lichtstrahlquelle (1), Mitteln (3, 13) für die Frequenzmodulation des Lichtstrahls, Mittel zur Aufspaltung und Wiederzusammenführung von Strahlen (5; 21, 22; 32), um die Aufspaltung des Lichtstrahls in zwei Komponenten mit einer gegenseitigen Phasenverschiebung zu bewirken, die von der zu messenden physikalischen Größe abhängt, und einem Detektor (8) zum Empfang der Komponenten des Lichtstrahls und zur Messung ihrer gegenseitigen Phasenverschiebung, **dadurch gekennzeichnet,** daß diese Lichtquelle (1) eine Breitbandquelle ist und daß die Mittel (3, 13) zur Modulation des Lichtstrahls durch ein Durchlaßbereichfilter (3) gebildet werden, das auf eine Frequenz zentriert ist, die entsprechend einem vorgegebenen Gesetz verändert wird.

4. Vorrichtung nach Anspruch 3, **dadurch gekennzeichnet,** daß das vorgegebene Gesetz ein Sinusform-Gesetz ist.

5. Vorrichtung nach Anspruch 3, **dadurch gekennzeichnet,** daß die Quelle (1) eine hochlumineszierende Laserquelle ist.

6. Vorrichtung nach Anspruch 3, **dadurch gekennzeichnet,** daß das Filter (3) ein Interferenzfilter ist.

7. Vorrichtung nach Anspruch 3, **dadurch gekennzeichnet,** daß das Filter (3) ein Fabry-Perot-Filter ist.

8. Vorrichtung nach Anspruch 3, **dadurch gekennzeichnet,** daß die Mittel zur Aufspaltung und Wiederzusammenführung von Strahlen (5; 21, 22; 32) einen optischen Strahlaufspalter (5) mit einer halbdurchlässigen Schicht (23) aufweisen, der den Lichtstrahl in eine reflektierte, auf einen Referenzspiegel (6) gerichtete Komponente und in eine durchgelassene, auf einen Targetspiegel (7) gerichtete Komponente aufspaltet, der in einem variablen Abstand von dem optischen Aufspalter (5) angeordnet werden kann und die Komponenten nach der Reflexion seitens der Spiegel (6, 7) wieder in einen einzigen Strahl zusammenführt, so daß die Phasenverschiebung der zusammengeführten Komponenten ein Maß für die variable Position des Targetspiegels (7) anzeigt.

9. Vorrichtung nach Anspruch 8, **dadurch gekennzeichnet,** daß der optische Strahlaufspalter (5) vom Biasdifferenz-Typ ist und zwei Viertelwellenschichten (9, 10) vorgesehen sind, die sich zwischen dem Strahlaufspalter (5) und den Spiegeln (6, 7) befinden.

10. Vorrichtung nach Anspruch 3, **dadurch gekennzeichnet,** daß die Mittel zur Aufspaltung und Wiederzusammenführung der Strahlen (5; 21, 22; 32) eine optische Referenzfaser (21) und eine optische Meßfaser (22) umfassen, die an den Enden durch Eingabe- und Ausgabekoppler (19, 20) verbunden sind, wobei die optische Meßfaser (22) einer physikalischen Größe (18) ausgesetzt ist, welche die Differenz zwischen der Ausbreitungszeit der Komponente des Lichtstrahls, der durch sie hindurchgeht, und derjenigen der Komponente des Lichtstrahls, der durch die Referenzfaser (21) hindurchgeht, bestimmen kann.

11. Vorrichtung nach Anspruch 3, **dadurch gekennzeichnet,** daß die Mittel zur Aufspaltung und Wiederzusammenführung der Strahlen (5; 21, 22; 32) eine optische Faser (32) mit einer hohen Doppelbrechung enthalten, die einer physikalischen Größe (28) ausgesetzt ist, die eine unterschiedliche Wirkung auf die Ausbreitungsgeschwindigkeiten der beiden Komponenten des Lichtstrahls, der sich entsprechend den beiden Biasmoden der Faser ausbreitet, haben kann.

Revendications

1. Procédé pour effectuer des mesures d'interférométrie absolue de grandeurs physiques, comprenant la délivrance d'un faisceau de lumière à partir d'une source (1), la modulation en fréquence dudit faisceau de lumière, le déphasage de composantes du faisceau de lumière en fonction de la grandeur physique à mesurer, la détection et la mesure du déphasage desdites composantes du faisceau de lumière ; caractérisé en ce que ladite délivrance est effectuée de manière à produire un faisceau lumineux à large bande, et en ce que ladite modulation est effectuée au moyen d'un procédé de filtrage passe-bande centré sur une fréquence qui est amenée à varier suivant une loi prédéterminée.

2. Procédé selon la revendication 1, caractérisé en ce que ladite loi prédéterminée et une loi sinusoïdale.

3. Dispositif pour mettre en oeuvre le procédé décrit dans la revendication 1, comprenant une source de faisceau de lumière (1), un moyen (3, 13) pour la modulation en fréquence dudit faisceau de lumière, un moyen pour diviser et recombiner des faisceaux (5 ; 21, 22 ; 32) pour provoquer la division du faisceau de lumière en deux composantes avec un déphasage mutuel fonction de la grandeur physique à mesurer, et un détecteur (8) approprié pour recevoir lesdites composantes du faisceau de lumière et pour mesurer leur déphasage mutuel ; caractérisé en ce que ladite source de lumière (1) est une source à large bande, et en ce que ledit moyen (3, 13) pour moduler le faisceau de lumière est constitué par un filtre passe-bande (3) centré sur une fréquence qui est amenée à varier en fonction d'une loi prédéterminée.

4. Dispositif selon la revendication 3, caractérisé en ce que ladite loi prédéterminée et une loi sinusoïdale.

5. Dispositif selon la revendication 3, caractérisé en ce que ladite source (1) est une source laser supra-luminescente.

6. Dispositif selon la revendication 3, caractérisé en ce que ledit filtre (3) est du type interférentiel.

7. Dispositif selon la revendication 3, caractérisé en ce que ledit filtre (3) est du type Fabry Perot.

8. Dispositif selon la revendication 3, caractérisé en ce que ledit moyen pour diviser et recombiner des faisceaux (5 ; 21, 22 ; 32) comprend un diviseur de faisceau optique (5) qui est une lame semi-transparente (23), qui divise le faisceau de lumière en une composante réfléchie dirigée vers un miroir de référence (6) et en une composante transmise dirigée vers un miroir cible (7) qui peut

être placé à une distance variable du diviseur optique (5) et qui recombine lesdites composantes en un faisceau unique après réflexion de la part desdits miroirs (6, 7), de sorte que le déphasage desdites composantes recombinées est indicatif de la position variable dudit miroir cible (7).

9. Dispositif selon la revendication 8, caractérisé en ce que ledit diviseur de faisceau optique (5) est du type à différence de polarisation, et en ce qu'il y a deux lames quart d'onde (6, 10) interposées entre ledit diviseur de faisceau (5) et lesdits miroirs (6, 7).

10. Dispositif selon la revendication 3, caractérisé en ce que ledit moyen pour diviser et recombiner des faisceaux (5 ; 21, 22 ; 32) comprend une fibre optique de référence (21) et une fibre optique de mesure (22) connectées aux extrémités par des coupleurs d'entrée et des sortie (19, 20), ladite fibre optique de mesure (22) étant soumise à une grandeur physique (18) appropriée pour déterminer la différence entre le temps de propagation de la composante du faisceau lumineux qui la traverse et celui de la composante du faisceau lumineux qui passe à travers la fibre de référence (21).

11. Dispositif selon la revendication 3, caractérisé en ce que ledit moyen pour diviser et recombiner des faisceaux (5 ; 21, 22 ; 32) comprend une fibre optique de référence (32), ayant une forte biréfringence, soumise à une grandeur physique (28) appropriée pour avoir un effet différent sur les vitesses de propagation des deux composantes du faisceau lumineux qui se propagent selon les deux modes de polarisation de fibre.

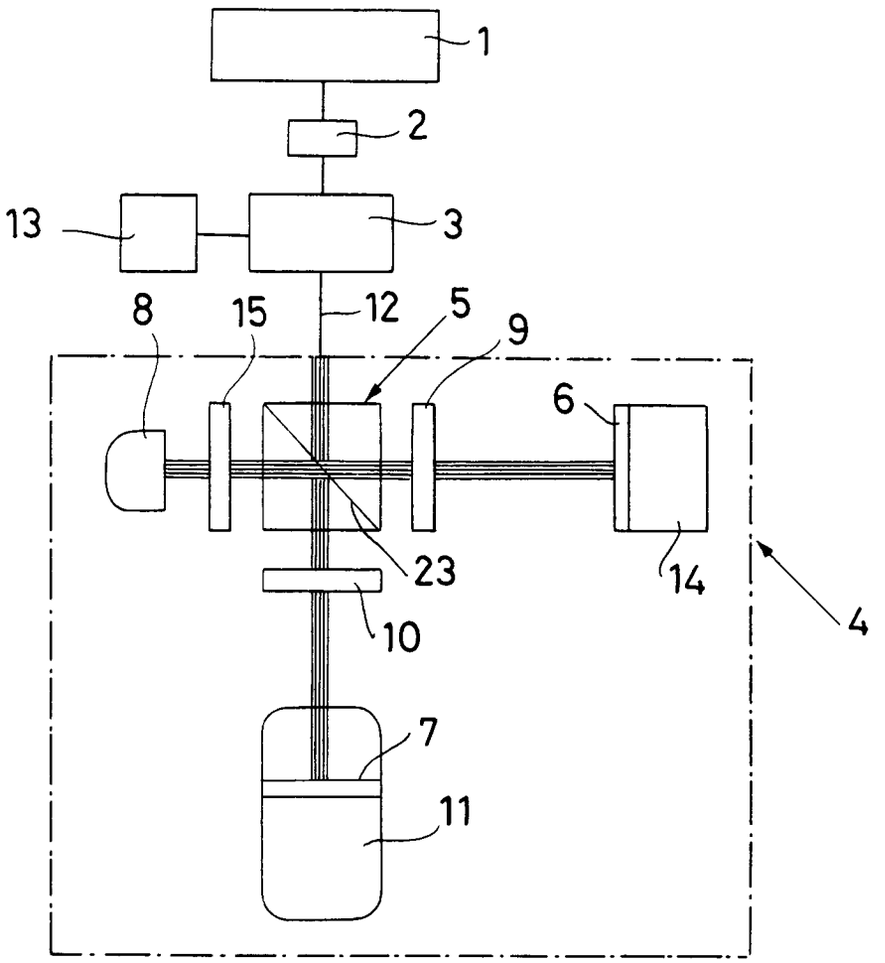


Fig.1

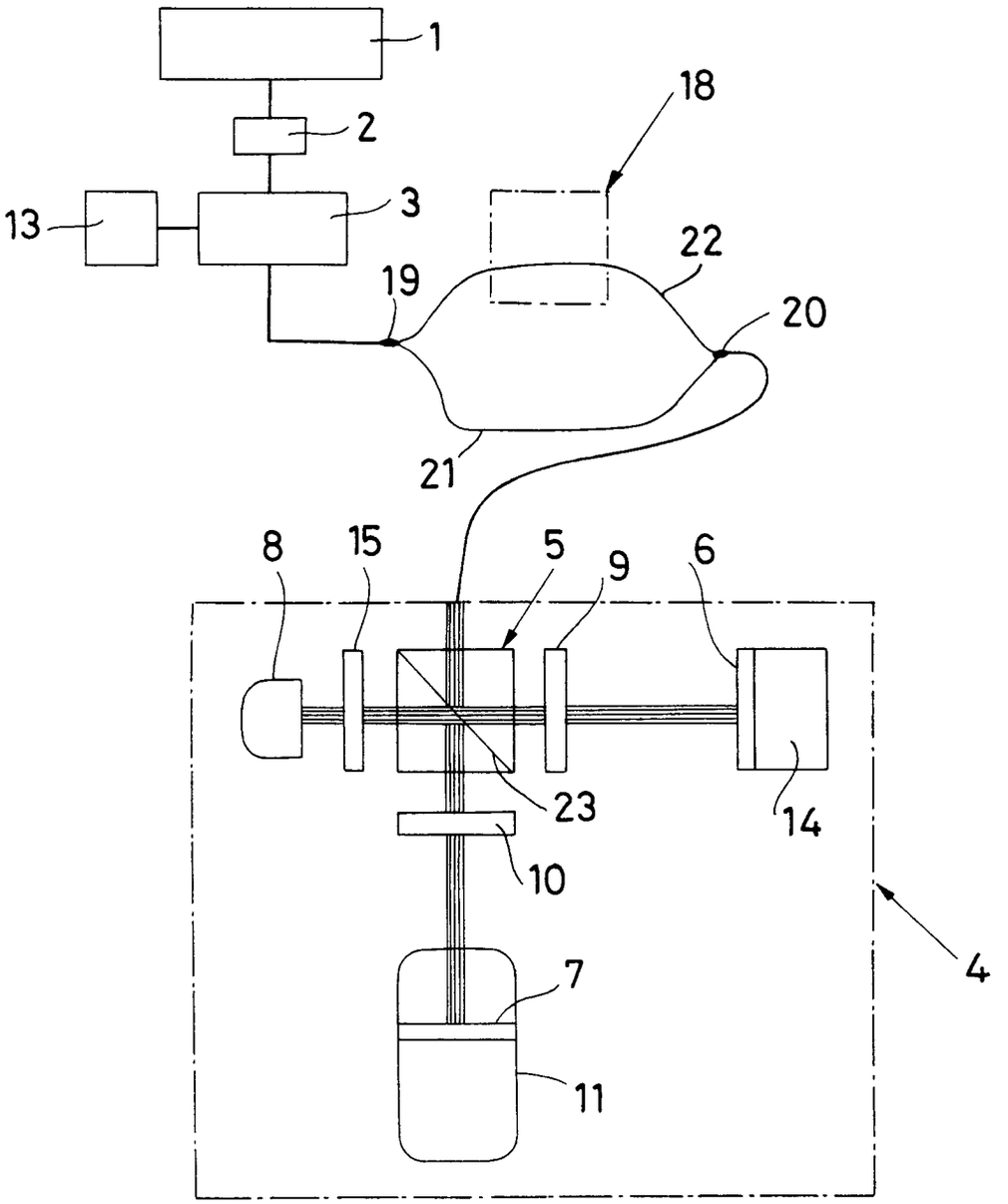


Fig.2

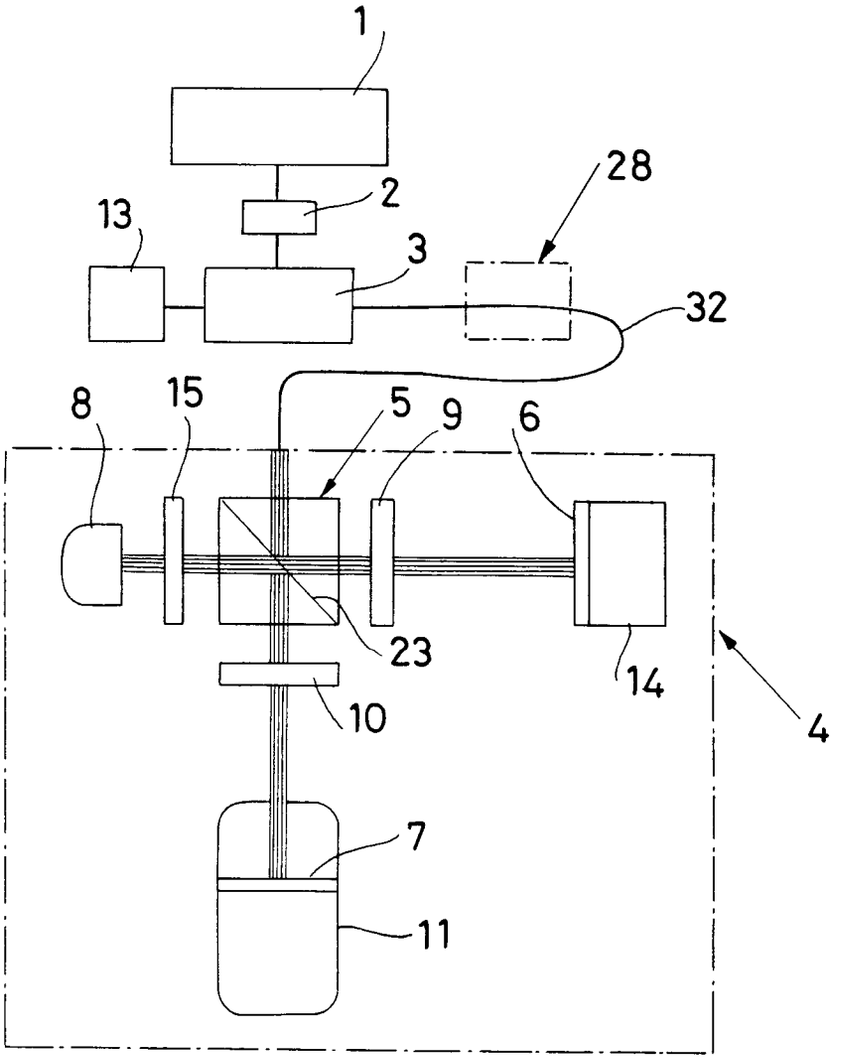


Fig.3